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Measurement of Neutron Total Cross Section of Ag and Sm at Pohang Neutron Facility

Guinyun KIM[1*], Youngseok LEE[1,2], Machrafi RACHID[1], Hossain AHMED[1], Dongchul SON[1], Vadim SKOY[2], Heng Sik KANG[2], In Soo KO[2], Moo Hyun CHO[2], Won NAMKUNG[2], Jong Hwa CHANG[3], Kun Joong YOO[3]

[1] *Institute of High Energy Physics, Kyungpook National University, 1370 Sankyuck-dong, Buk-gu, Taegu 702-701, Korea*

[2] *Pohang Accelerator Laboratory, Pohang University of Science and Technology, San 31, Hyoja-dong, Nam-gu, Pohang 790-784, Korea*

[3] *Nuclear Data Evaluation Laboratory, Korea Atomic Energy Research Institute, PO Box 105, Yusung, Dajeon 305-600, Korea*

The neutron total cross section of natural Ag and Sm has been measured in the energy region from 0.1 eV to 100 eV by the neutron time-of-flight method at Pohang Neutron Facility, which consists of an electron linear accelerator, a water-cooled Ta target with a water moderator, and an 11 m long time-of-flight path. A ^{6}Li-ZnS(Ag) scintillator with a diameter of 12.5 cm and a thickness of 1.6 cm has been used as a neutron detector and metallic plates of Ag and Sm samples have been used for the neutron transmission measurement. The background level has been determined by using notch-filters of Co, In, and Cd sheets. In order to reduce the gamma rays from Bremsstrahlung and that from neutron capture, we have employed a neutron-gamma separation system based on their different pulse shapes. The present measurements are in general agreement with the previous ones and the evaluated data in ENDF/B-VI. The resonance parameters of Ag isotopes (^{107}Ag and ^{109}Ag) have been extracted from the transmission data by using the SAMMY code.

KEYWORDS: total cross section, Ag, Sm, neutron time-of-flight, 0.1 eV to 100 eV energy range, Pohang Neutron Facility, Ta target, electron linear accelerator, resonance parameter, SAMMY fitting

I. Introduction

The measurement of neutron cross sections gives basic information for the study of neutron interactions with nuclei. Precise measurements of neutron cross sections are of great importance for the safety design of nuclear reactors and for the evaluation of the neutron flux density and the energy spectrum around a reactor.

Pulsed neutrons based on an electron linear accelerator (linac) is a powerful tool to measure the energy-dependent cross sections with high resolution by using the time-of-flight (TOF) method covering the energy range from thermal neutrons to a few tens of MeV. The Pohang Neutron Facility (PNF) based on a 100-MeV electron linac was proposed in 1997 and constructed at the Pohang Accelerator Laboratory on December 1999[1)]. The PNF consists of an electron linac, a water-cooled Ta target, and an 11 m long TOF path. The characteristics of PNF are described elsewhere [2)].

In the present work, the total cross section of natural Ag and Sm has been measured in the neutron energy range between 0.1 eV and 100 eV by the neutron TOF method at the PNF. The measured result has been compared with other measurements[3,4)] and the evaluated data in ENDF/B-VI[5)]. The resonance parameters for Ag isotopes (^{107}Ag and ^{109}Ag) were determined from the fitting of transmission data by using the Multilevel R-Matrix code SAMMY[6)].

*Corresponding author, Tel. +82-53-950-6328, Fax. +82-955-53 - 5356, E-mail: gnkim@knu.ac.kr

II. Experimental Procedure

The experimental arrangement for the transmission measurements is described elsewhere[2)]. The target is located in the position where the electron beam hits its center. To reduce the gamma-flash generated by the electron burst in the target, the target is placed in 55 mm away from the center of neutron guide. The target was composed of ten Ta plates with a diameter of 4.9 cm and an effective thickness of 7.4 cm. There was a 0.15 cm water gap between Ta plates in order to cool the target effectively. The housing of the target was made of titanium. This target was set at the center of a cylindrical water moderator contained in an aluminum cylinder with a thickness of 0.5 cm, a diameter of 30 cm and a height of 30 cm. The water level in the moderator was 3 cm above the target surface.

The neutron guide tubes were constructed by stainless steel with two different diameters of 15 cm and 20 cm and disposed vertically to the electron beam. The neutron collimation system was mainly composed of H_3BO_3, Pb and Fe collimators, which were symmetrically tapered from 10 cm diameter at the beginning, 5 cm in the middle position where the transmission sample was located, and 8 cm diameter at the end of guide tube where the neutron detector was placed. There is 1.8 m thick concrete between the target and the detector room.

The transmission samples were placed at the midpoint of the flight path. Metallic plates of natural Ag (10×10 cm^2 in area by 0.5 mm thickness) and Sm (5×5 cm^2 in area by 1.0 mm thickness) samples have been used for the neutron transmission measurement. A set of notch filters of Co, In, and Cd plates with 0.5 mm, 0.2 mm, and 0.5 mm in thickness respectively, was also used for the background measurement and the energy calibration.

The sample changer consists of a disc accompanied with 4 holes; each hole is of 8 cm in diameter, which matches the hole of collimator in the neutron beam line. The sample changer controlled remotely by CAMAC module. The diameter between centers of two opposite holes is 31 cm.

The neutron detector was located at a distance of 10.81 m from the photo-neutron target. A ^{6}Li-ZnS(Ag) scintillator BC702 from Bicron (Newbury, Ohio) with a diameter of 12.5 cm and a thickness of 1.6 cm mounted on an EMI-93090 photomultiplier was used as a detector for the neutron TOF spectrum measurement.

During the experiment, the electron linac was operated with a repetition rate of 10 Hz, a pulse width of 1.0 μs and the electron energy of 60 MeV. The peak current in the beam current monitor located at the end of the second accelerator section is above 50 mA, which almost is the same as that in the target.

III. Data Acquisition and Analysis

Figure 1 shows the configuration of the data acquisition system used in our measurement. Two different data acquisition systems were used for neutron TOF spectra measurements: one for NIM based system and the other for CAMAC based system. The main purpose of the NIM based system is neutron–gamma separation and the parallel accumulation of the neutron TOF spectra if necessary. The dynode signal from a BC702 scintillator was connected through an ORTEC-571 amplifier (AMP) to an ORTEC-552 pulse-shape analyzer (PSA) in order to use a neutron-gamma separation. A fast NIM signal from "A" output of the PSA was delayed by 60 ns and used as a start signal of an ORTEC-567 time-to-amplitude converter (TAC). The "B" output signal from the PSA was used as a stop signal of the TAC. TAC output was connected to an ORTEC-550A single channel analyzer (SCA). One of SCA output signals was used as a stop signal of a 150 MHz Turbo MCS (Time Digitizer), the other was sent to a CAMAC based system. The start signal of Time Digitizer signal came from the RF trigger. The Time Digitizer was operated by a 16384-channel mode with a 0.5 μs width per channel.

The CAMAC based system consists of a data acquisition part and a control part of the sample changer. The SCA output signal of the NIM based system was connected to the detector number encoder (DNE) through the NIM/TTL converter. The DNE allows the data taking up to four detectors simultaneously. The output of the DNE gives a stop signal for the time encoder which operates with 4096 channels and a minimal dwell time of 0.5 μs width per channel.

The 10-Hz RF trigger signal for the modulator of the electron linac was connected to a gate and delay generator (G&D Gen.); the output signal was used as a start signal of the time encoder. One of signals from the time encoder was sent to 16 K capacity memory module (MEM 16K), which collects the TOF spectra during the measurement

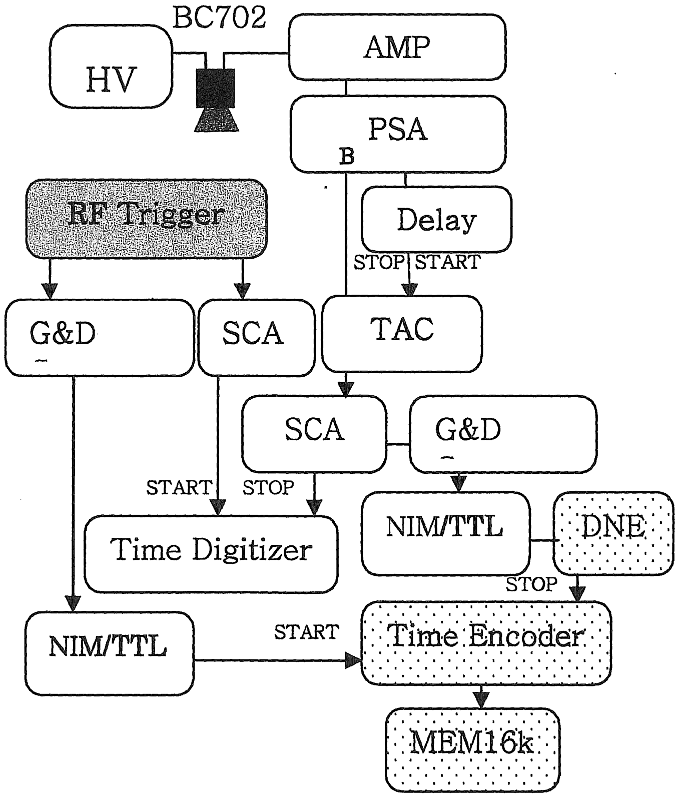

Fig. 1. Block diagram of data acquisition system

We could estimate the background level by using resonance energies of the neutron TOF spectra of notch-filters of Co, In, and Cd as shown in **Fig. 2**. The magnitude of the background level has been interpolated between the black resonances by using the fitting function $F(I) = a + b \cdot e^{-I/c}$, where a, b, and c are constants and I is the channel number of the time digitizer. The background fitting function was also shown in **Fig. 2**.

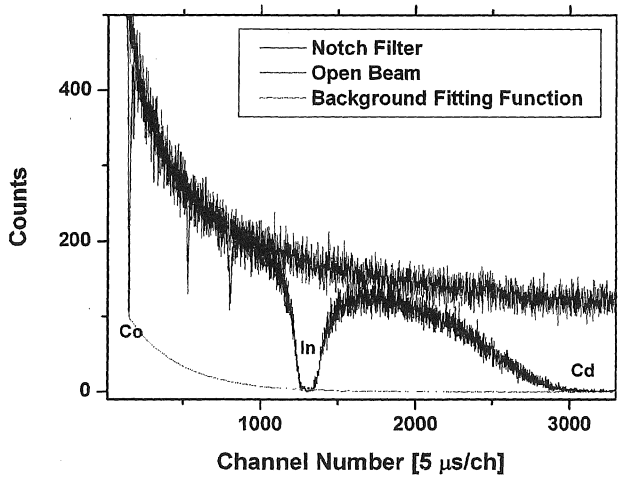

Fig. 2. Background measurements with the notch filters.

The measurements were performed with Ag and Sm samples simultaneously. Two other free positions of the sample changer were empty to collect the neutron TOF spectra without sample (open beam). The positions of samples were chosen in the following sequence: Ag – empty – Sm – empty. The exposition times for both Ag and Sm were 15 minutes (9000 pulses of PNF linac), for each free position it was 7.5 minutes. Thus, the durations of each sample and total open beam measurements were equal. The interleaving sequence of free position of sample changer was chosen to minimize influence of slow or/and small variation of the neutron beam intensity. If the beam intensity variations or its drift was fast or/and big, then these partial measurements were excluded from the total statistics. Total data taking times for Ag and Sm are 65 hours respectively and with the same times for open beams.

The neutron total cross section is determined by measuring the transmission of neutrons through the sample. The transmission rate of neutrons at i-th group energy E_i is defined as a fraction of incident neutrons passing through the sample compared to that one in the open beam. Thus, the neutron total cross section is related to the neutron transmission rate $T(E_i)$ as follows:

$$\sigma(E_i) = -\frac{1}{\sum_j N_j} \ln T(E_i) \ , \qquad (1)$$

$$T(E_i) = \frac{[I(E_i) - IB(E_i)]/M}{[O(E_i) - OB(E_i)]/MB} \qquad (2)$$

where N_j is the atomic density per cm^2 of j-th isotope in the sample. $I(E_i)$ and $O(E_i)$ are the foreground counts for sample in and out, $IB(E_i)$ and $OB(E_i)$ are the background counts for sample in and out, and M and MB are their monitor counts, respectively. The monitor counts are obtained by integrating the TOF counts corresponding to the relevant energy region. In this analysis, we assumed each monitor counts were equal during the data taking period.

IV. Results and Discussion

The total cross sections of natural Ag and Sm were obtained in the energy range from 0.1 eV to 100 eV by using the neutron TOF method. The present measurements for the neutron total cross sections of Ag and Sm are compared with other data measured by other groups[3,4] and the evaluated data in ENDF/B-VI[5]. The present measurements without any corrections are generally in good agreement with other data and the evaluated one as shown in **Fig. 3**. However, the present measurement of Sm is rather higher than the evaluated one due to the thick sample.

There are many resonance peaks in the neutron total cross sections for Ag and Sm. In order to get the resonance parameters of each resonance peak, we fit the transmission data for Ag with the SAMMY code[6].

Resolution function $R_{GE}(E,E')$ used in this calculation is the convolution of Gaussian and exponential function and its mathematical expression is as follows:

$$R_{GE}(E,E') = \frac{1}{\Delta_E \Delta_G \sqrt{\pi}} \int_{E-\Delta E_S}^{\infty} dE^0 e^{\frac{-(E^0-(E-\Delta E_S))}{\Delta_E}} e^{\frac{-(E'-E^0)^2}{\Delta_G^2}} \qquad (3)$$

where the width of Gaussian resolution function Δ_G is given by

$$\Delta_G = E[aE+b]^2, \qquad (4)$$

and the width of exponential resolution function Δ_E is given by

$$\Delta_E = cE^{3/2}. \qquad (5)$$

The energy shift ΔE_S, which is automatically determined in the SAMMY, is introduced in order to locate the maximum of the broadening function at $E' = E$. The constant values of a, b, and c are 1.3645×10^{-6} eV^{-1}, 9.1281×10^{-6}, and 6.3969×10^{-4} eV$^{-1/2}$, respectively.
The resonance parameters for ^{107}Ag and ^{109}Ag isotopes have been obtained from the SAMMY fitting and listed in **Table 1** and **Table 2**. Quantity J/ l is the spin of a particular resonance.

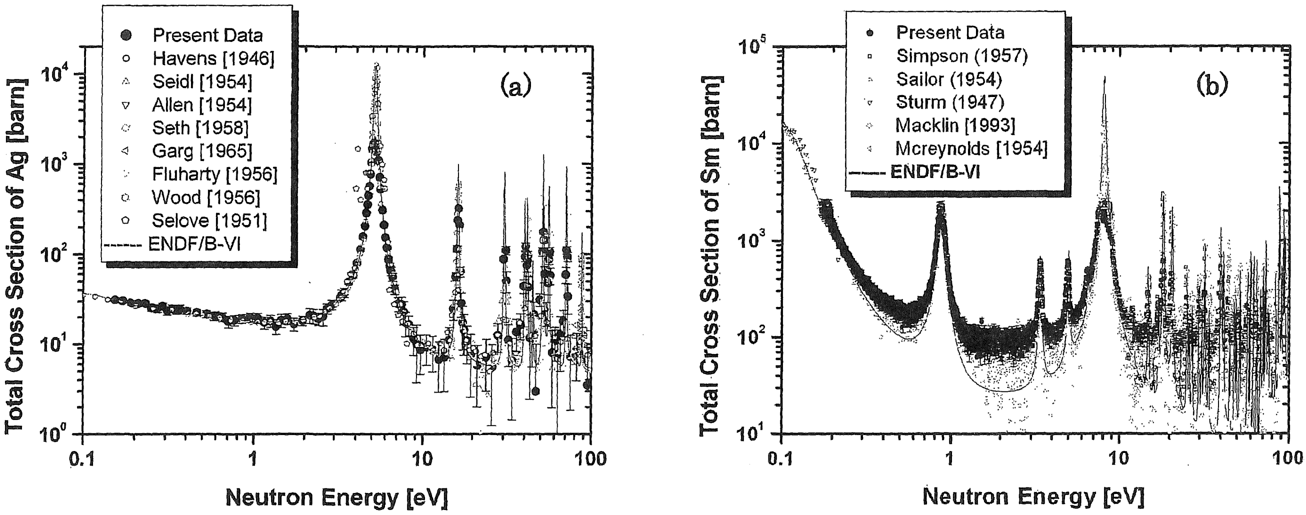

Fig.3. Comparison of the experimental total cross sections of (a) Ag and (b) Sm with the evaluated data in the neutron energy region between 0.01 and 100 eV.

Table. 1. Resonance parameters for ^{107}Ag

J/l	E[eV]	Γ_n [meV]	Γ_γ [meV]
0/0	16.423±0.004	7.545±0.112	363.54±10.64
1/1	18.899±0.140	0.0001±0.00001	100.00±10.00
1/1	20.323±0.147	0.0002±0.00002	99.99±10.00
1/1	35.826±0.233	0.0004±0.00004	100.00±10.00
1/0	41.726±0.026	2.5219±0.1273	163.78±15.68
1/1	42.751±0.276	0.0047±0.0005	100.00±10.00
1/0	45.264±0.118	1.8478±0.1701	150.12±14.94
1/0	51.756±0.018	9.7141±0.2916	314.97±24.32

Table 2. Resonance parameters for ^{109}Ag

J/l	E[eV]	Γ_n [meV]	Γ_γ [meV]
1/0	5.186±0.001	5.9511 ±0.0004	345.27±3.61
1/0	30.674±0.011	4.4958±0.1135	432.99±24.17
1/1	32.694±0.214	0.0092±0.0009	100.09±10.01
1/0	40.492±0.020	3.7147±0.1484	231.62±19.89
0/0	56.048±0.032	19.559±0.898	171.55±16.32

In **Fig. 4**, the measured total cross section of natural Ag in the neutron energy range from 1 eV to 65 eV was compared with the SAMMY fitting results. The SAMMY prediction of total cross section and the present data are in good agreement with each other with χ^2/N=1.41.

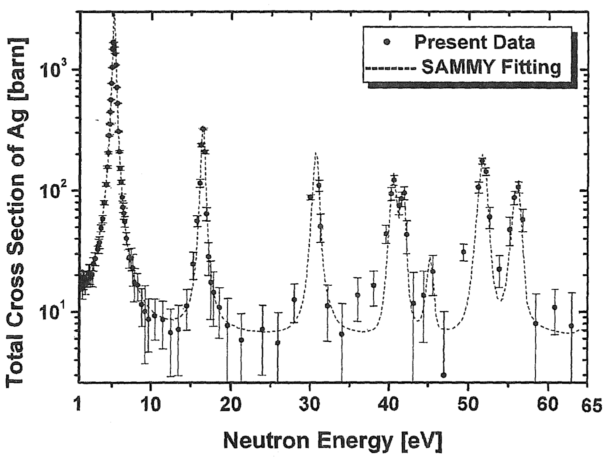

Fig. 4. Comparison of the measured total cross sections of natural Ag with the predicted ones from the SAMMY fitting.

V. Conclusion

The neutron total cross sections of natural Ag and Sm have been measured in the neutron energy region from 0.1 eV to 100 eV by using a ^{6}Li-ZnS(Ag) scintillator and the neutron TOF technique at the Pohang Neutron Facility. The present measurement for natural Ag is in good agreement with the evaluated data in ENDF/B-VI and the previous measurements. However, the result for natural Sm is higher than the evaluated data due to the thick sample used in this measurement.

The resonance parameters of Ag isotopes have been determined by the fitting the transmission data.

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